Study of polarized gluon distributions in diffractive reactions at HERA

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Abstract: We consider the dependencies of spin asymmetries in the diffractive J/Ψ and $Q\bar{Q}$ leptoproduction at HERA energies on the structure of the pomeron-proton coupling. It is shown that it is difficult to study the spin structure of the pomeron coupling with the proton from the A_{ll} asymmetry. The A_{lT} asymmetry is an appropriate object for this investigation.

Now the pomeron nature is a problem of topical interest due to the progress in analysis of diffractive processes at HERA [1]. Investigation of the diffractive vector meson and $Q\bar{Q}$ production should give fertile information on the pomeron structure and on the gluon distribution at small x. The diffractive J/Ψ and heavy $Q\bar{Q}$ production have a significant role here. The predominant contribution in such processes is determined by a color singlet t -channel exchange (pomeron). In the QCD-inspired models, the pomeron is modeled by two gluons [2]. The two–gluon couplings with the proton in diffractive processes at small x can be expressed in terms of skewed gluon distribution in the nucleon $\mathcal{F}_X(X+\Delta)$ with $X \sim (Q^2+M_V^2)/W^2, \Delta \ll X$, where $X+\Delta$ is a fraction of the proton momentum carried by the outgoing gluon, and the difference between the gluon momenta (skewedness) is equal to X [3]. Generally, these distributions are not connected with ordinary gluon distributions.

The proposed HERA spin program gives a unique possibility to study polarized skewed gluon distributions in the nucleon which are connected with the spin dependent pomeron coupling. The spin structure of the pomeron is an open problem now. In the QCD-based models, when the gluons from the pomeron couple to a single quark in the hadron, the effective pomeron coupling $V_{h\!P}^\mu = \beta_{h\!P}\gamma^\mu$ appears which looks like a $C = +1$ isoscalar photon vertex [4]. The spin-dependent pomeron coupling can be obtained if one considers together with the Dirac form factor $\propto \gamma^\mu$ the Pauli form factor [5] in the electromagnetic nucleon current. We use in calculations the following form of two–gluon coupling with the proton [6]:

$$V_{p\!P}^{\mu\nu}(p, t, x_P) = 4p^\mu p^\nu A(t, x_P) + (\gamma^\mu p^\nu + \gamma^\nu p^\mu) B(t, x_P). \tag{1}$$

Here x_P is a fraction of initial proton momenta carried by the pomeron. The term proportional to B represents the pomeron coupling that leads to the non-flip amplitude. The A function is the spin–dependent part of the pomeron coupling that produces spin–flip effects nonvanishing at high-energies. The absolute value of the ratio of A to B is proportional to the ratio of helicity-flip and non-flip amplitudes. It has been found in [7, 8] that $\alpha = |A|/|B| \sim 0.1 - 0.2\,\mathrm{GeV}^{-1}$ and has a weak energy dependence.

A convenient tool to study the spin-dependent pomeron structure might be polarized diffractive leptoproduction reactions. We shall consider here the spin asymmetry of the J/Ψ and $Q\bar{Q}$ production. The cross section of these reactions has the following important parts: leptonic and hadronic tensors and the amplitude of the $\gamma^\star I\!\!P \to J/\Psi(Q\bar{Q})$ transition. The form of the leptonic tensor is quite simple. The structure of the hadronic tensor for the vertex (1) is discussed in Ref. [6]. The spin-average and spin dependent cross sections with parallel and antiparallel longitudinal polarization of a lepton and a proton are determined by the relation $\sigma(\pm) = (\sigma(\rightleftarrows) \pm \sigma(\rightrightarrows))/2$. These cross sections can be expressed in terms of spin-average and spin dependent value of the lepton and hadron tensors. The cross section of the J/Ψ leptoproduction can be written in the form

$$\frac{d\sigma^\pm}{dQ^2 dy dt} = \frac{|T^\pm|^2}{32(2\pi)^3 Q^2 s^2 y}. \tag{2}$$

For the spin-average amplitude square we find [6]

$$|T^+|^2 = N((2 - 2y + y^2)m_J^2 + 2(1-y)Q^2)s^2|B|^2[|1 + 2m\alpha|^2 + |\alpha|^2|t|]I^2. \tag{3}$$

Here N is a known normalization factor $\alpha = |A|/|B|$ and I is the integral over transverse momentum of the gluon. The term proportional to $(2 - 2y + y^2)m_J^2$ in (3) represents the contribution of a virtual photon with transverse polarization. The $2(1-y)Q^2$ term describes the effect of longitudinal photons.
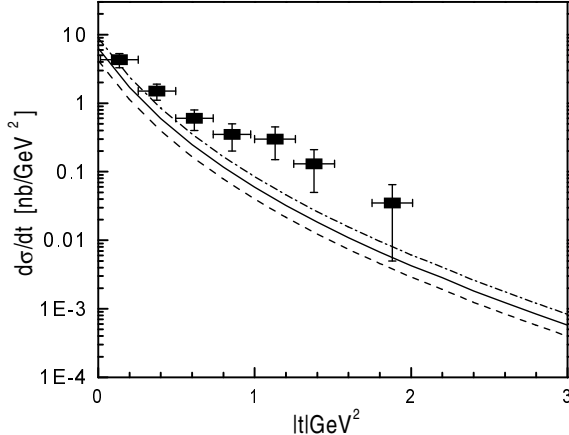

Figure.1 *The differential cross section of the J/Ψ production at HERA energy: solid line -for $\alpha = 0$; dot-dashed line -for $\alpha = 0.1\,GeV^{-1}$; dashed line -for $\alpha = -0.1\,GeV^{-1}$.*
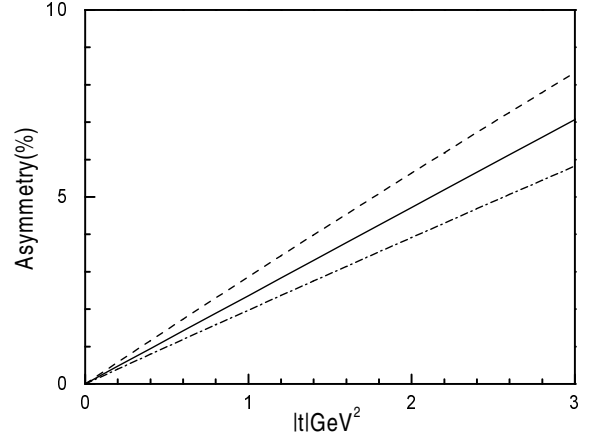
Figure.2 *The predicted A_{ll} asymmetry of the J/Ψ production at HERMES: solid line -for $\alpha = 0$; dot-dashed line -for $\alpha = 0.1\,GeV^{-1}$; dashed line -for $\alpha = -0.1\,GeV^{-1}$.*

We shall integrate the cross sections (2) over y and Q^2 with $Q^2_{max} \sim 4\text{GeV}^2$

$$\frac{d\sigma^\pm}{dt} = \int_{y_{min}}^{y_{max}} dy \int_{Q^2_{min}}^{Q^2_{max}} dQ^2 \frac{d\sigma^\pm}{dQ^2 dy dt}. \tag{4}$$

The cross section for the J/Ψ production at HERA energy $\sqrt{s} = 300 GeV^2$ is shown in Fig.1. The spin-average cross sections are sensitive to α but the shape of all curves is the same. Thus, it is difficult to extract information about the spin–dependent part of the pomeron coupling from the spin–average cross section of the diffractive vector meson production.

Similar calculation has been done for the spin–dependent part of the cross section. As a result, the following form of asymmetry is found [6]:

$$A_{ll} = \frac{\sigma(-)}{\sigma(+)} \sim \frac{|t|}{s} \frac{(2 - \bar{y})(1 + 2m\alpha)}{(2 - 2\bar{y} + \bar{y}^2)\left[(1 + 2m\alpha)^2 + \alpha^2|t|\right]}. \tag{5}$$

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The predicted asymmetry of the J/Ψ vector meson production for HERMES as a function α is shown in Fig. 2. The asymmetry is equal to zero in the forward direction. Thus, the ordinary gluon distribution ΔG cannot be extracted from A_{ll} in agreement with the results of [9]. The predicted asymmetry does not vanish for nonzero $|t|$. The value of the asymmetry for $\alpha \neq 0$ is dependent on the A–term of the pomeron coupling. However, the sensitivity of the asymmetry to α is not very strong. Thus, it will not be so easy to study the spin structure of the pomeron coupling with the proton from the A_{ll} asymmetry of the diffractive J/Ψ production.

Similar calculations have been done for the heavy $Q\bar{Q}$ diffractive leptoproduction. As previously, we have included in our analyses the graphs where the gluons from the pomeron couple to a different quark in the loop as well to the single one. This provides the gauge-invariant scattering amplitude. The obtained A_{ll} asymmetry is proportional to x_p like for the vector meson production and has a weak energy dependence (here x_p is typically of about $.05 - .1$). The cross section integrated over the pomeron momentum transfer was calculated because the recoil proton is usually not detected in diffractive experiments. The obtained asymmetry is quite small and does not exceed 1-1.5%. It has a week α dependence and does not vanish for $\alpha = 0$ as in the J/Ψ production. The estimated Q^2 dependence of A_{ll} asymmetry of the diffractive open charm ($c\bar{c}$) production is shown in Fig. 3. Note that the smallness of the asymmetry is caused by the strong cancellation in $\Delta\sigma$ between the graphs where the gluons couple to the single and a different quark in the loop. Similar calculation for the Donnachie-Landshoff model of the pomeron, where only the planar graphs appear, provides the asymmetry which is about 10%. [10]
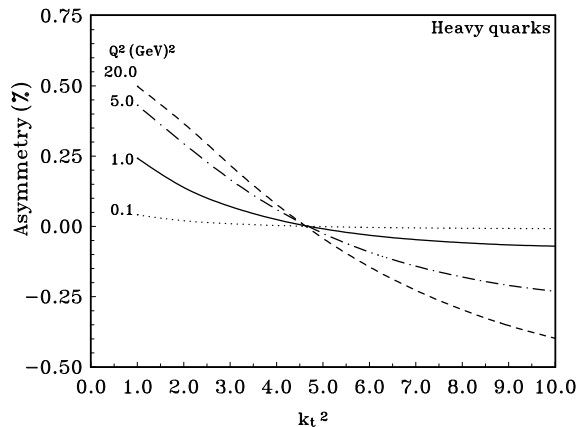

Figure.3 *The predicted Q^2 dependence of A_{ll} asymmetry for the $c\bar{c}$ production at HERA for $\alpha = 0.1\,GeV^{-1}$, $x_p=0.1$, $y=0.5$.*
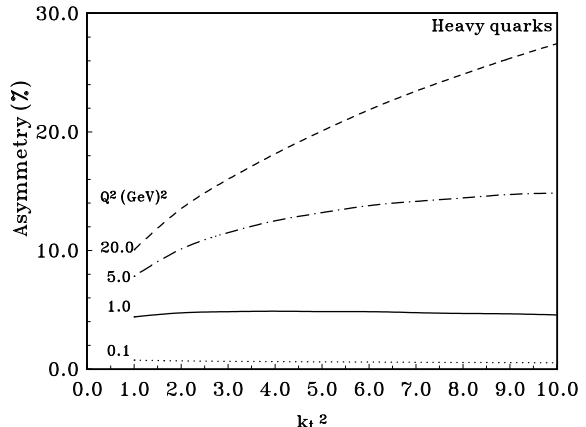
Figure.4 *The predicted Q^2 dependence of A_{lT} asymmetry for the $c\bar{c}$ production at HERA for $\alpha = 0.1\,GeV^{-1}$, $x_p=0.1$, $y=0.5$.*

Another important object which can be studied at polarized HERA is the A_{lT} asymmetry with longitudinal lepton and transverse proton polarization. It has been found that A_{lT} asymmetry is proportional to the scalar production of the proton spin vector and the jet momentum. Thus, the asymmetry integrated over the azimuthal jet angle is zero. We have calculated the A_{lT} asymmetry for the case when the proton spin vector is perpendicular to the lepton scattering plane and the jet momentum is parallel to this spin vector. This is impossible explicitly in the experiment and the integration over some region of the angle between spin vector and jet momentum should be done. Then, the additional factor $\int_{-\Theta}^{\Theta} \cos(\theta)d\theta / \int_{-\Theta}^{\Theta} d\theta$ appears which is about 0.98 for $\Theta = 20^o$. The estimated Q^2 dependence of the A_{lT} asymmetry integrated over t for $\alpha = 0.1\mathrm{GeV}^{-1}$ is shown in Fig. 4. The predicted asymmetry is huge and has a strong $k_\perp^2$

dependence. The large value of A_{lT} asymmetry is caused by the fact that it does not have a small factor x_p as a coefficient.

In the present report, the polarized cross section of the diffractive hadron leptoproduction at high energies has been studied. As a result, connection of the spin–dependent cross section in the diffractive production with the pomeron coupling has been found. Generally, the function B should be determined by the spin–average and the function A - by the polarized skewed gluon distribution in the proton. We predict not small value of the A_{ll} asymmetry of the diffractive vector meson production at the HERMES energy. The predicted A_{ll} asymmetry in the $Q\bar{Q}$ leptoproduction is smaller than 1.5%. The nonzero asymmetry for $\alpha = A/B = 0$ is completely determined by the γ^α term in the pomeron coupling (1). The A_{ll} asymmetry in diffractive processes for nonzero momentum transfer has been found to be dependent on the A term of the pomeron coupling which has a spin dependent nature. However, the sensitivity of asymmetry to the α–ratio is quite weak. Thus, the A_{ll} asymmetry in diffractive reactions is not a good tool to study the polarized gluon distributions of the proton and spin structure of the pomeron. Otherwise, it has been found not small A_{lT} asymmetry in diffractive $Q\bar{Q}$ production. This asymmetry is proportional to α and can be used to obtain direct information about the spin–dependent part of the pomeron coupling A. The A_{lT} asymmetry is an appropriate object to investigate the spin structure of pomeron coupling and the skewed polarized gluon structure of the proton.

We can conclude that the pomeron coupling structure can be analysed in diffractive processes. So, the important test of the spin structure of QCD at large distances can be carried out by studying diffractive reactions in future polarized experiments at HERA.

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